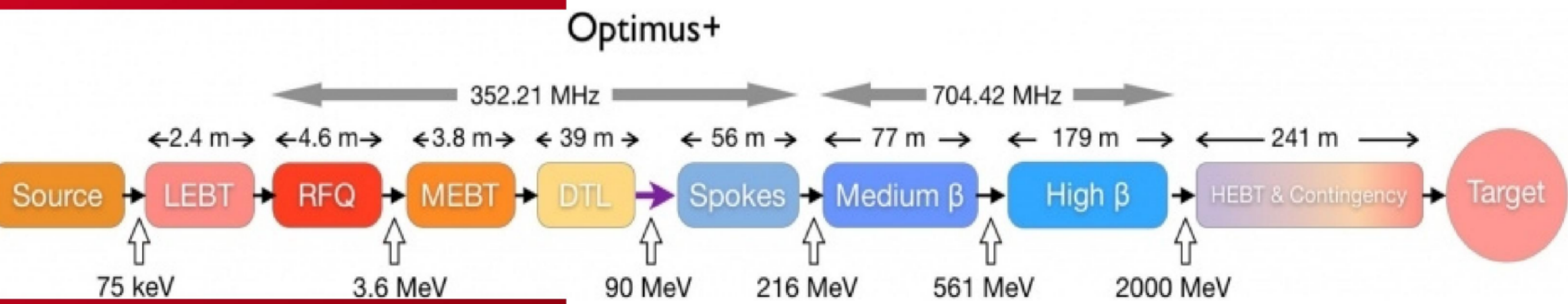
DE LA RECHERCHE À L'INDUSTRIE

SPACE CHARGE EFFECTS STUDIES FOR THE ESS COLD LINAC BEAM PROFILER



F. Belloni[1], F. Benedetti[1], J. Marroncle[1], P. Abbon[1], G. Coulloux[1], F. Gougnaud[1], C. Lahonde-Hamdoun[1], P. Le Bourlout[1], Y. Mariette[1], J. P. Mols[1], V. Nadot[1], L. Scola[1], C. Thomas[2]

[1]CEA-Saclay, Gif sur Yvette, France
[2]ESS, Lund, Sweden

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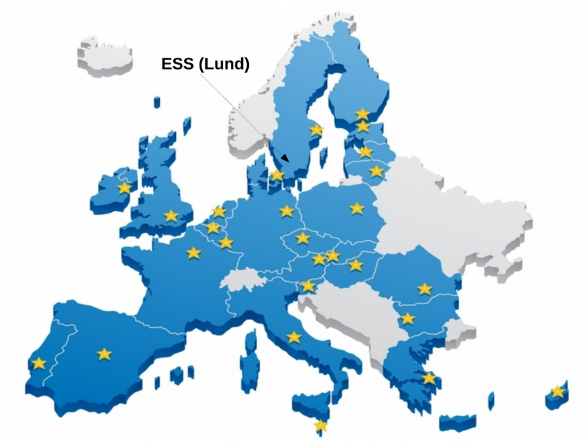
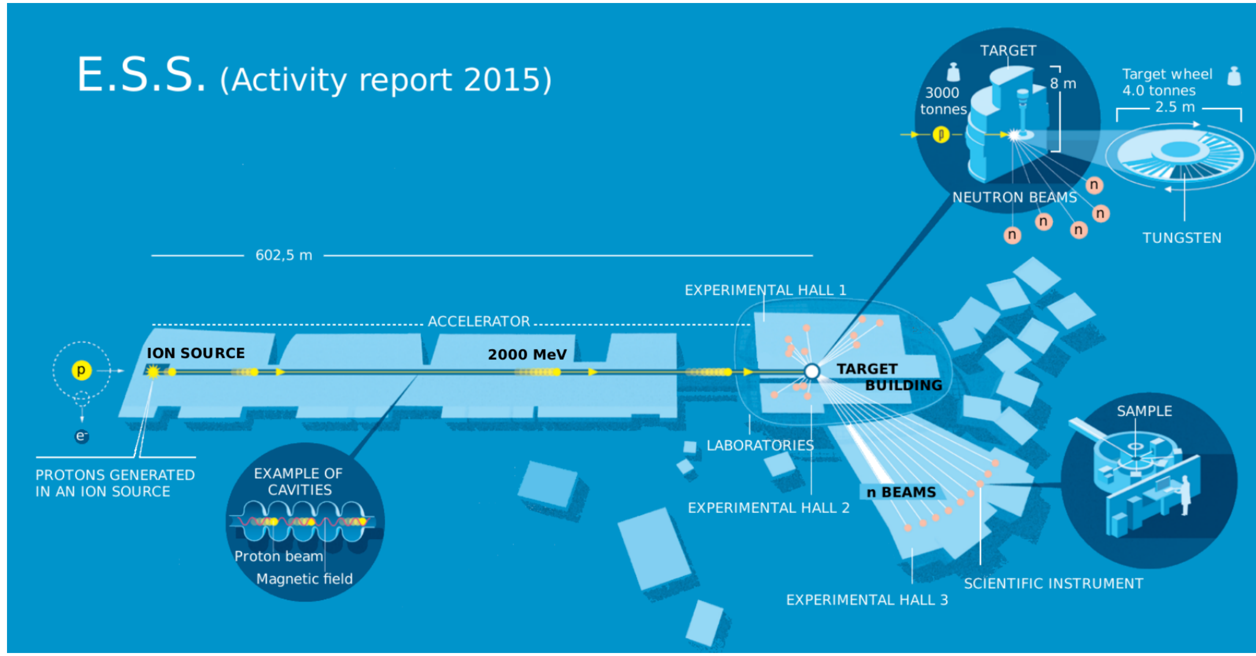
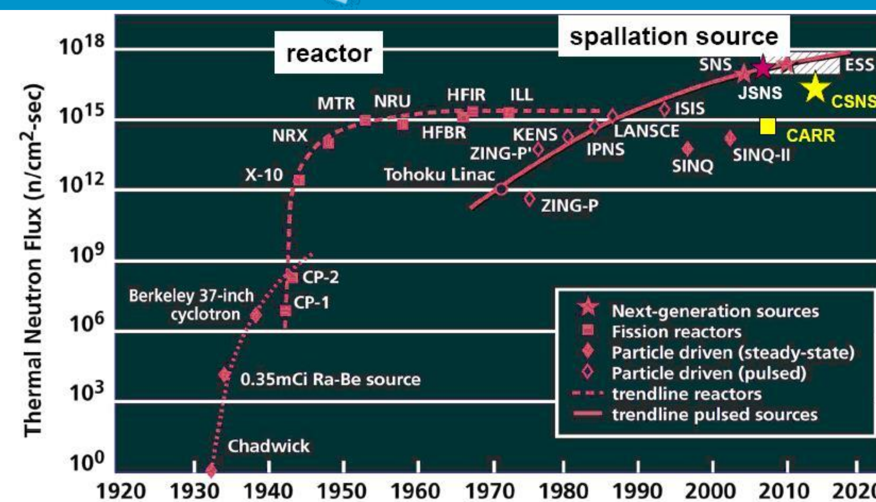
E.S.S





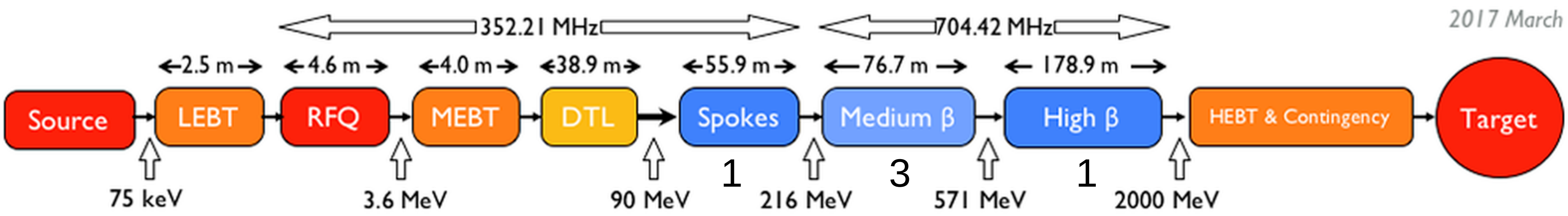
- Life Science
- Material Science
- Imaging
- Fundamental Particle Physics



Why a non-interceptive beam profiler?

TRANSVERSE PROFILE MEASUREMENTS FOR:

- supporting the tuning of the beam



REQUIRERMENTS for the BEAM TRANVERSE PROFILER:

- Stand high proton beam intensity (I_{peak} = 62.5 mA, P_{peak} = 125 MW)
- Have minimum impact on the the proton beam (avoid H^+ scattering/induced nucl. reactions)
- No cooling forseen
- Provide enough statistics (capability of measuring 1 profile per pulse at nominal vacuum conditions)

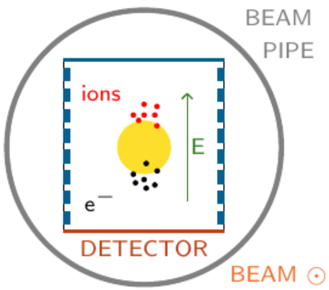
NPM / IPM

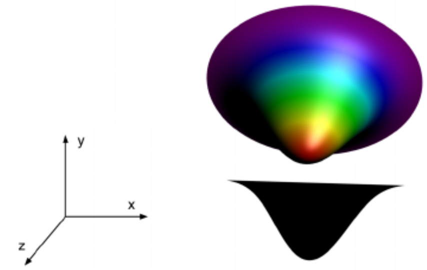
- The total measurement error in the RMS extension of the beam must amount to less than ± 10%. (ESS L4 requirement)

Working principle and issues:

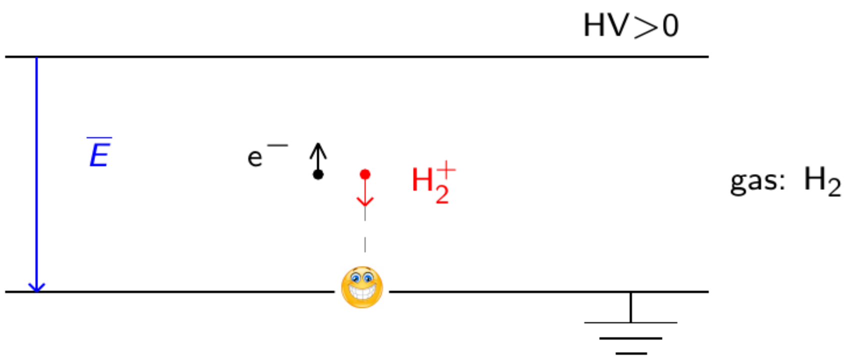
IPM: Ionisation Profile Monitor

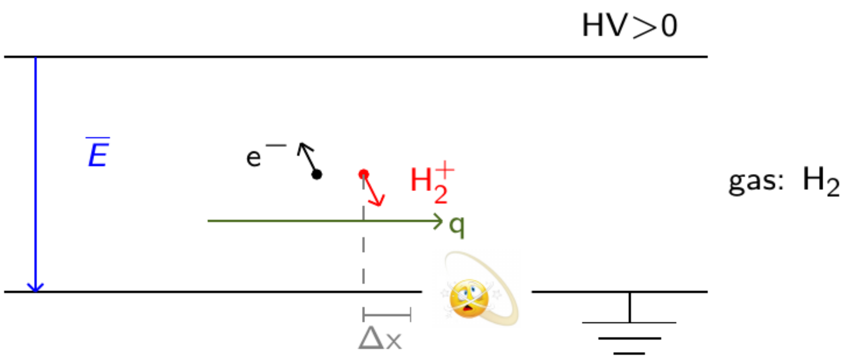
- The proton beam ionises the residual gas
- E separates e⁻/ionised molecules
- Charge collection on read-out





SPACE CHARGE EFFECTS:



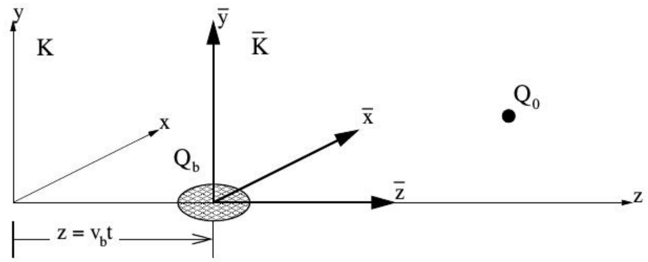


POSSIBLE CORRECTION METHODS

- Add magnetic field ✗
- High electric field ✓ ✗
- Software correction ✓

Space charge effect estimation:

General idea:



- A Gaussian bunch with charge Q_b is moving with velocity v_b along the z-axis in the lab. frame K.
- The bunch is at rest w.r.t. the co-moving frame K.
- The Φ generated by Q_b is calculated in the co-moving frame → $\nabla^2 \Phi(\bar{x}, \bar{y}, \bar{z}) = -\frac{1}{\epsilon_0} \rho(\bar{x}, \bar{y}, \bar{z})$.
- The E field generated by Q_b is calculated in the co-moving frame → $\bar{\boldsymbol{E}} = -\boldsymbol{\nabla} \Phi$
- Through Lorentz transformations, the E field in K is translated into an electromagnetic field in K.

$$\boldsymbol{E} = \begin{pmatrix} E_x \\ E_y \\ E_z \end{pmatrix} = \begin{pmatrix} \gamma_b \bar{E}_x \\ \gamma_b \bar{E}_y \\ \bar{E}_z \end{pmatrix}, \quad \boldsymbol{B} = \begin{pmatrix} -\gamma_b \beta_b \bar{E}_y / c \\ \gamma_b \beta_b \bar{E}_x / c \\ 0 \end{pmatrix} = \frac{\beta_b}{c} \begin{pmatrix} -E_y \\ E_x \\ 0 \end{pmatrix}.$$

- **F** = Q_0(**E** + **v** x **B**) ⇒ acceleration ⇒ speed ⇒ displacement … therefore trajectory of Q_0 in the elm field generated by Q_b.

Implementation (ESS core + CEA development & optimisation):

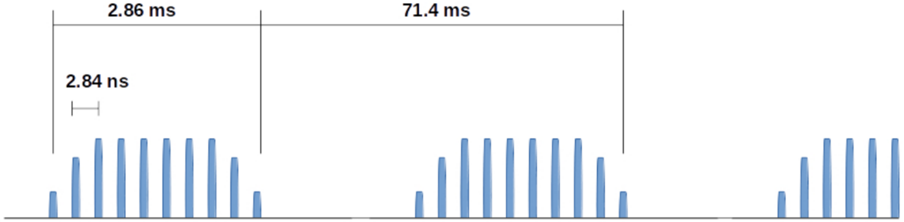
- 10^4 test particle Q_0 are generated in the center of the IPM and tracked as described above.
- The SCE is given by the difference between the initial and final RMS of the Q_0 distribution

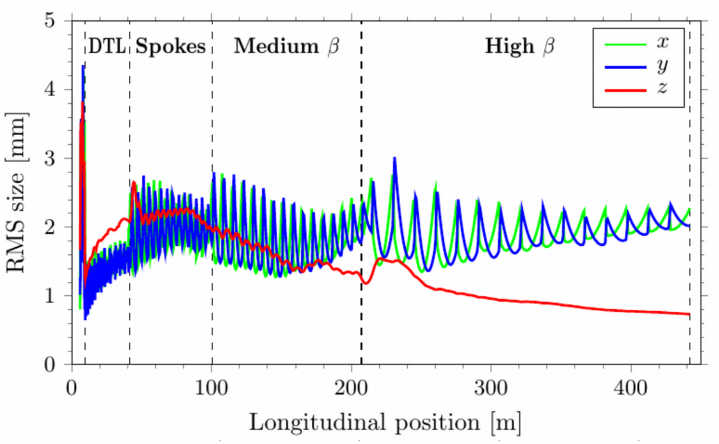
R. Wanzenberg, Nonlinear Motion of a Point Charge in the 3D Space Charge Field of a Gaussian Bunch.

Parameters on which SCE depend:

- Beam "structure" (intensity, spatial spread, energy)?
  - Energy: [90, 2000] MeV
  - Current peak: 62.5 mA
  - Pulse length: 2.86 ms
  - Pulse frequency: 14 Hz (duty cycle 4%)
  - Bunch frequency: 352.31 MHz

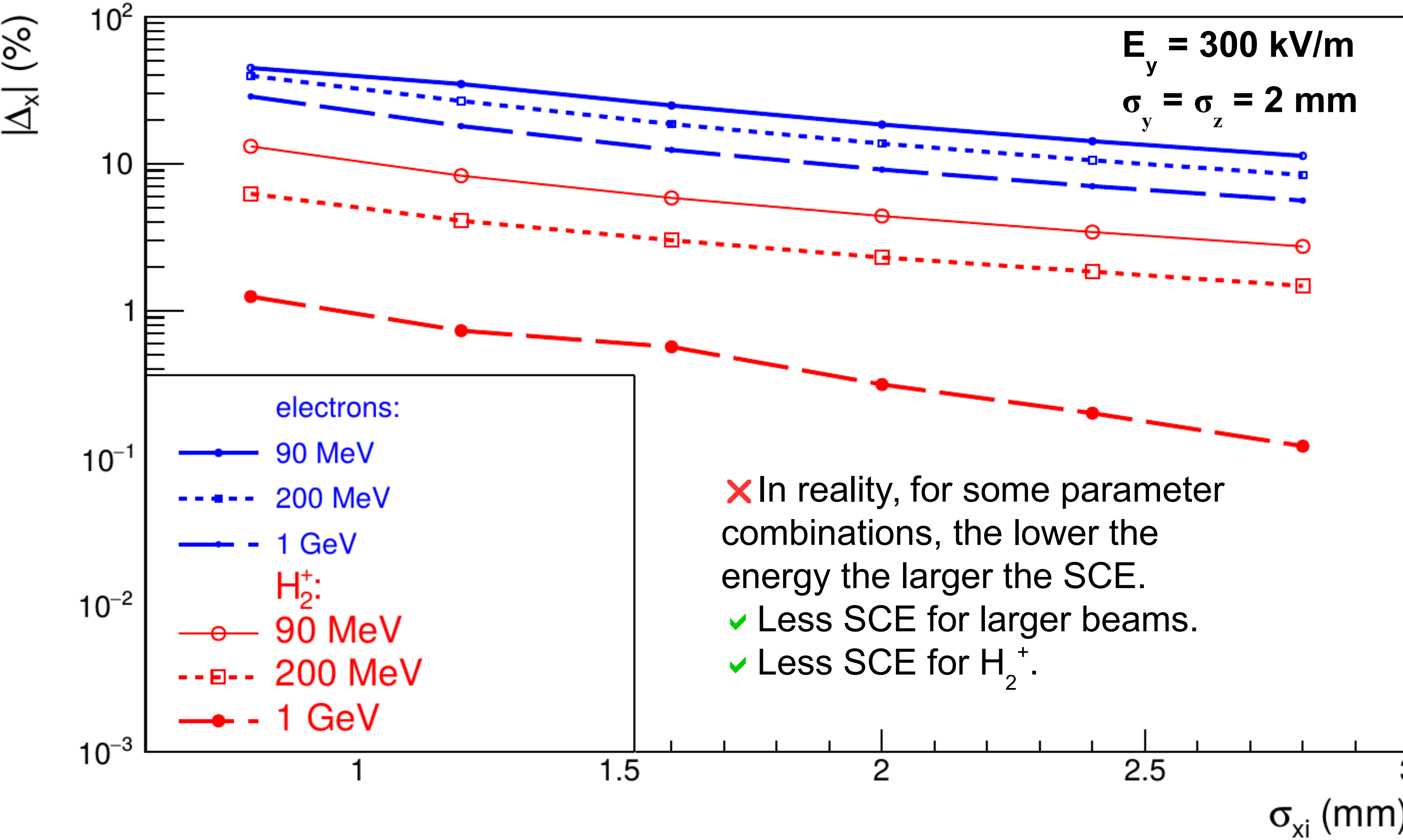
  - σ_x: [1.4 , 3] mm
  - σ_y: [1.4 , 3] mm
  - σ_z: [0.8 , 2.8] mm





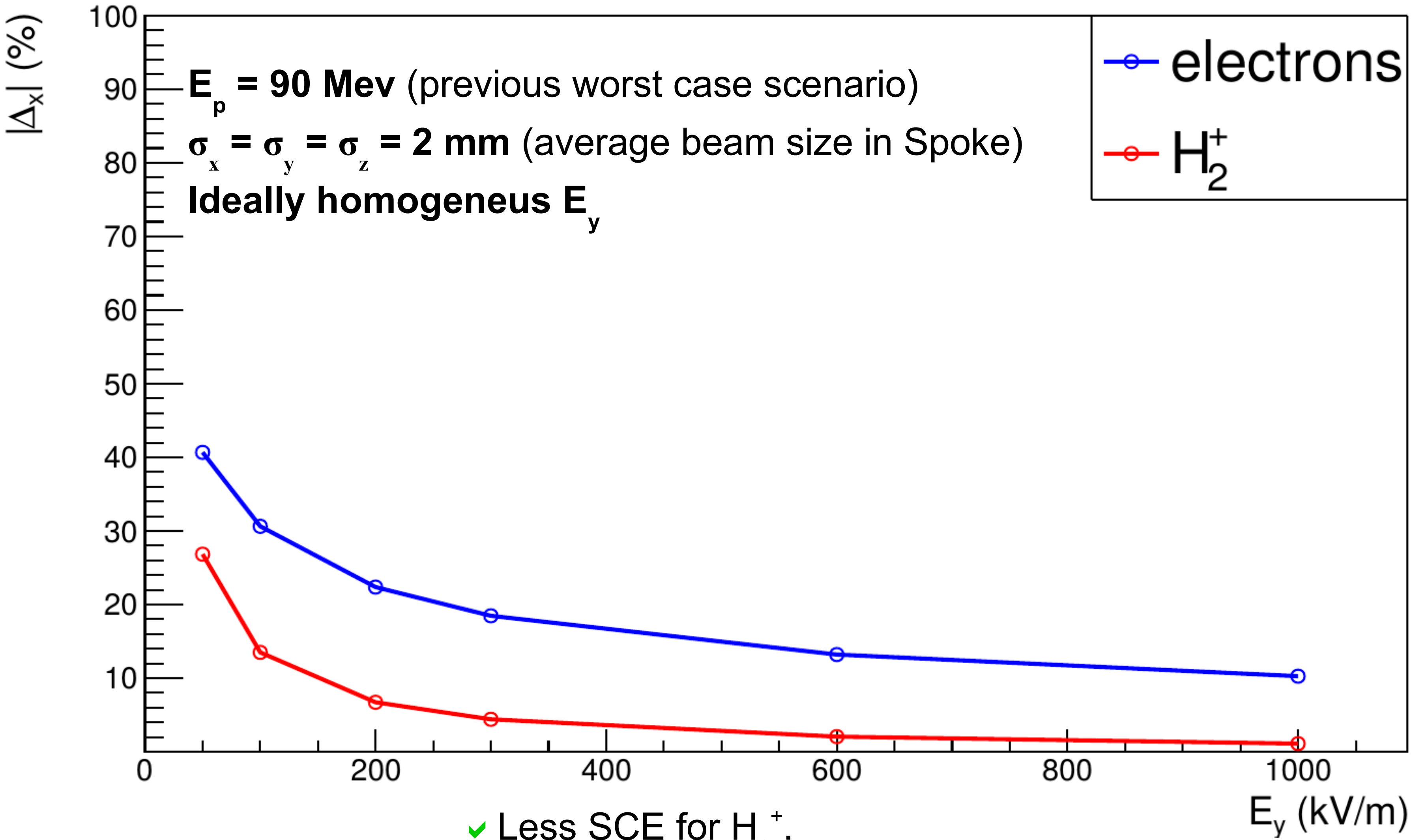
- E field?
- Nature of the tracked ion ⇒ residual gas composition?
  - Nominal gas composition: H_2 (79%), CO (10%), CO_2 (10%), N_2 (1%)
- Initial momenta distribution of electrons/ionised molecules?

Beam energy influence:



- ✗ In reality, for some parameter combinations, the lower the energy the larger the SCE.
- ✓ Less SCE for larger beams.
- ✓ Less SCE for H_2^+.

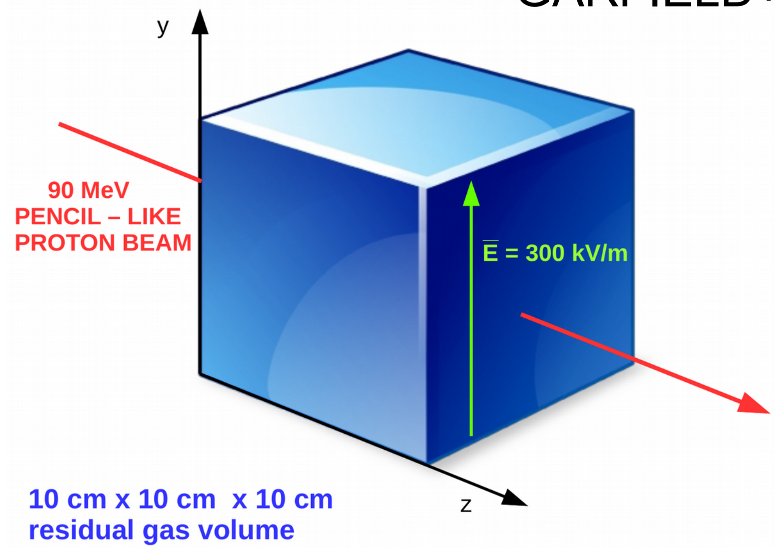
Electric field influence:

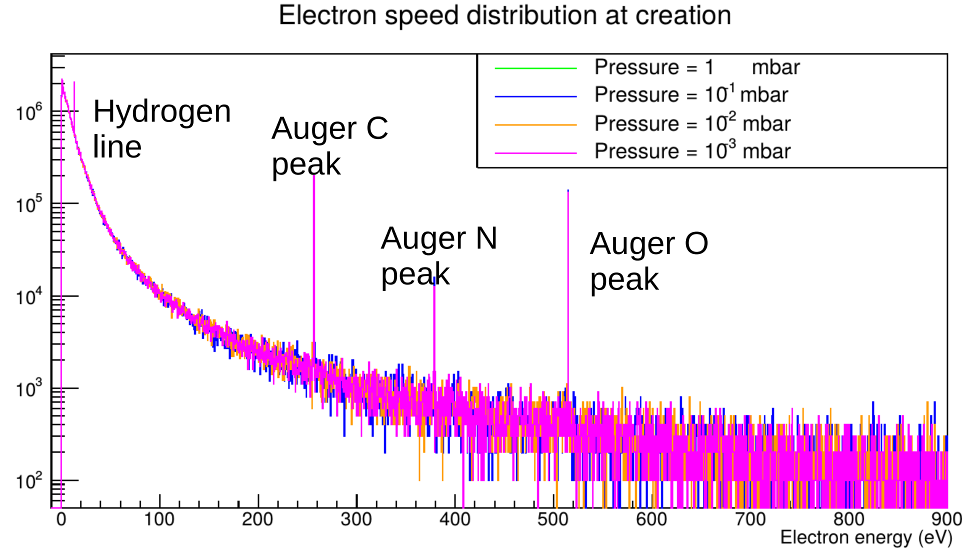


- Less SCE for H_2^+.
- Less SCE for higher electric fields.

Initial momenta influence (1/2):

GARFIELD++ simulations

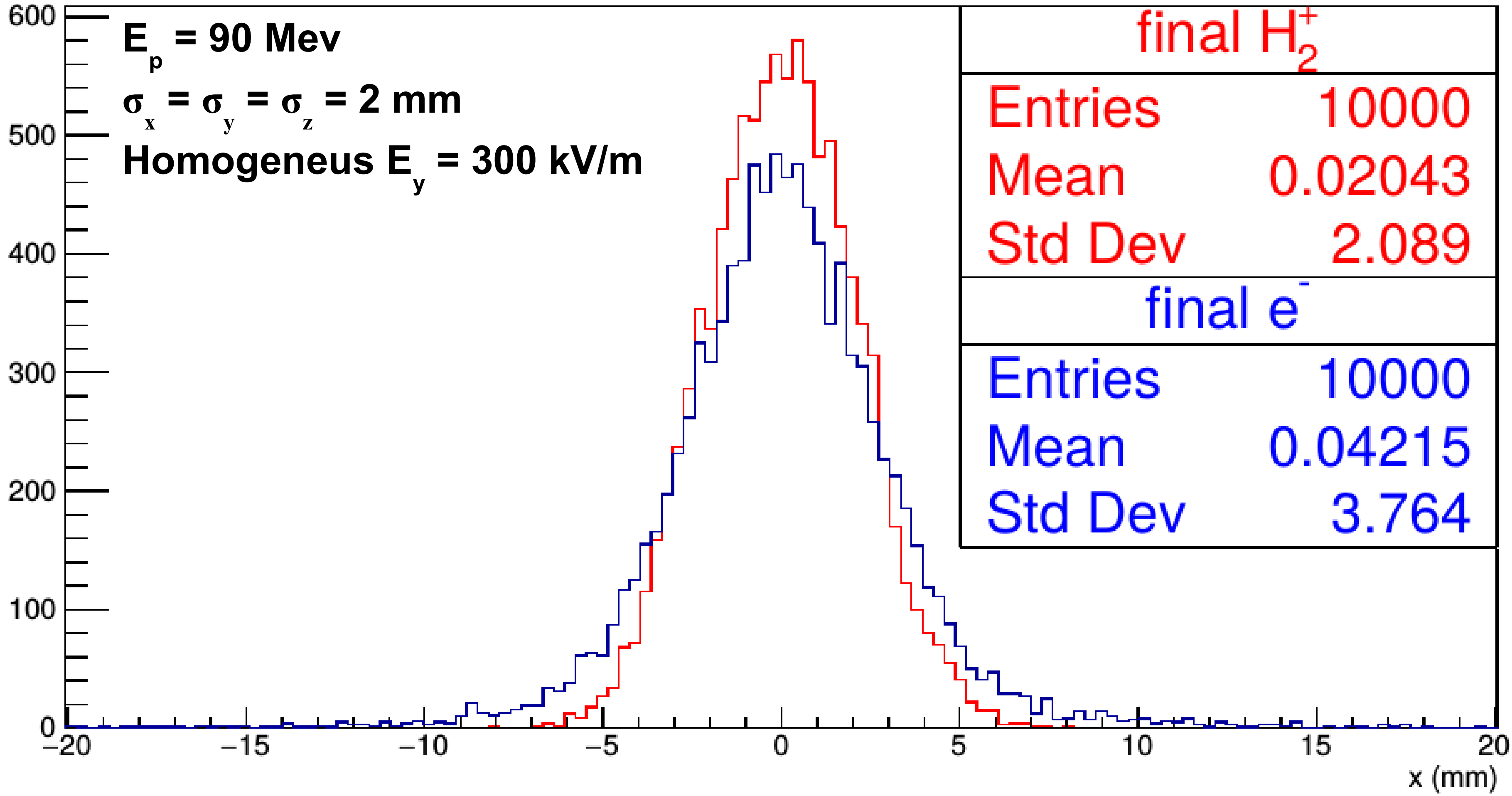




Electrons:

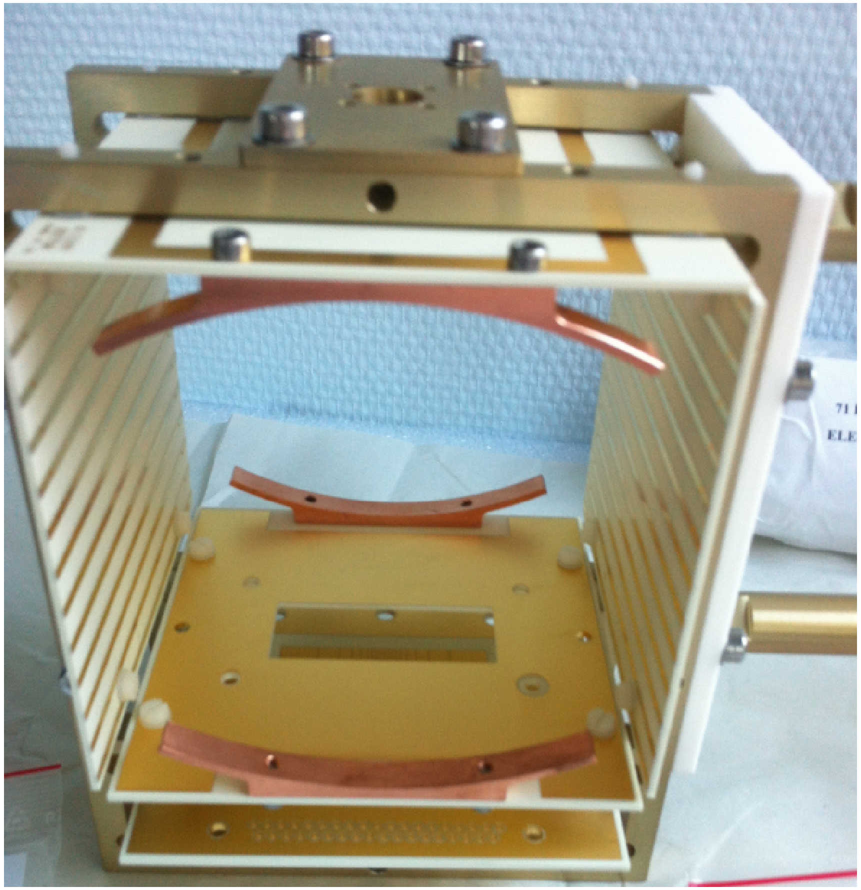
- Azimuthal angle φ uniformly sampled in [0, 2π)
- Emitted preferentially orthogonally to the z axis
- Ionised molecules (assumption): $v_e = \frac{m_{ion}}{m_e} v_{ion}$

Initial momenta influence (2/2):



- ✔ Less SCE for H_2^+.

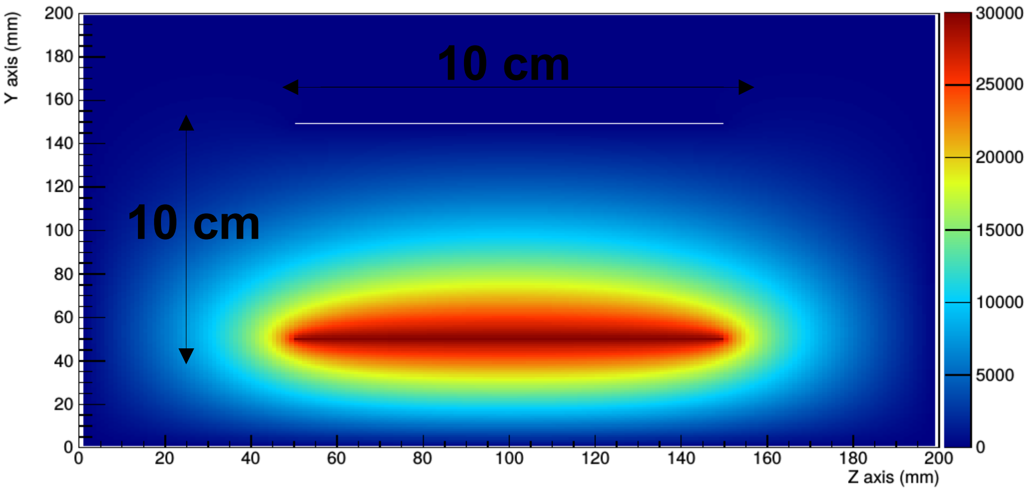
Electric field homegeneity influence:



COMSOL simulations of the El field in the IPM:

- The value of the resistors was optimized with COMSOL in order to get the best electric field uniformity
- Different sets of resistors were chosen for different potential difference configurations

Potential field map example:



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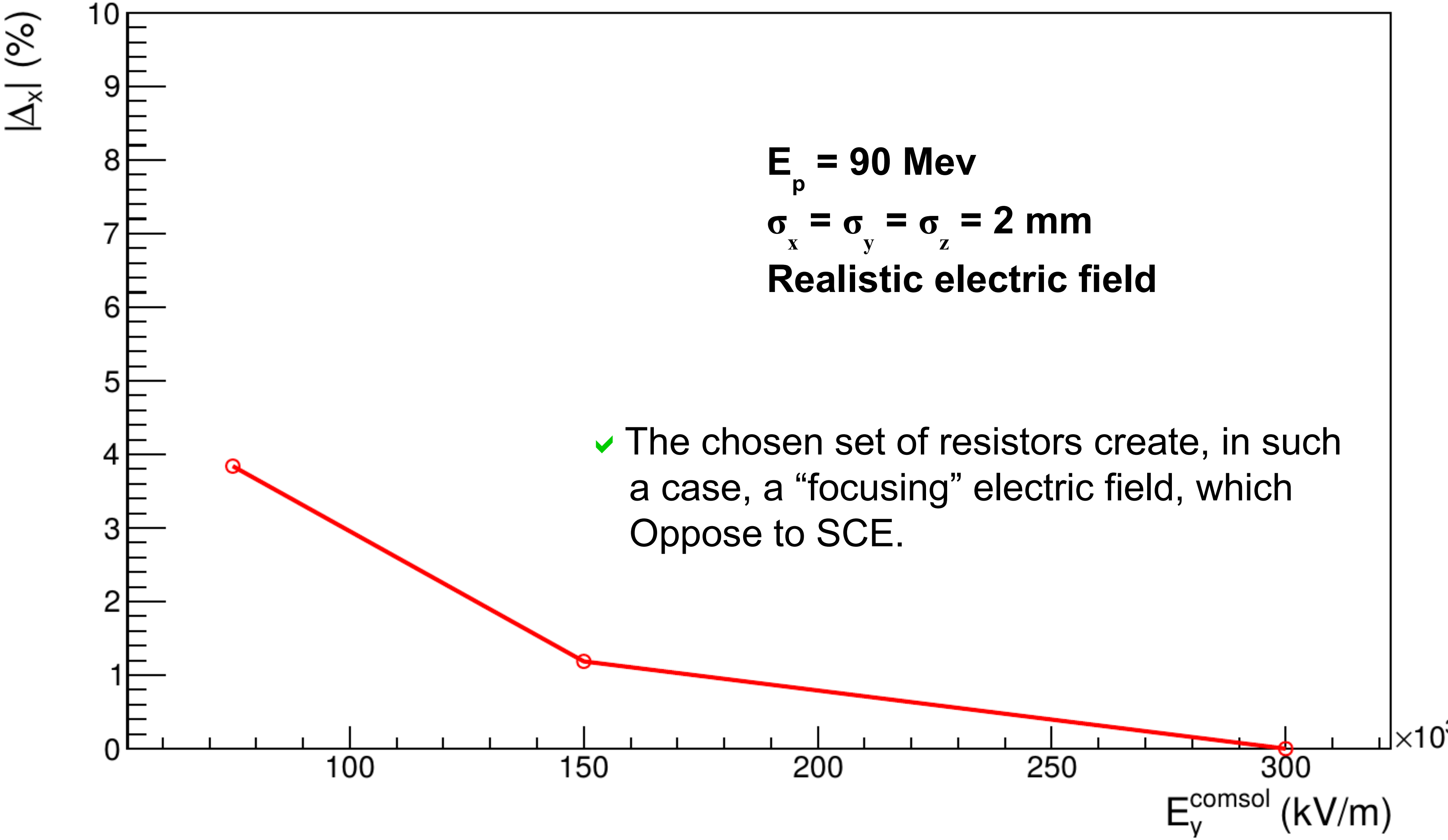

E_p = 90 Mev

$\sigma_x = \sigma_y = \sigma_z$ = 2 mm

Realistic electric field

- The chosen set of resistors create, in such a case, a “focusing” electric field, which Oppose to SCE.

Conclusions:

TO MINIMIZE THE SCE

- IPM used in ion configuration
- Initial momenta distribution unimportant only for massive ionisitation products
- High electric field
- Properly “chosen” real electric field.

IF MEASURES TO MINIMIZE THE SCE ARE FOLLOWED, NO CORRECTION IS NEEDED TO MEET THE L4 ESS REQUIREMENTS

REMINDER:
the total measurement error in the RMS extension of the beam must amount to less Than ± 10%. (L4 ESS requirement)

Conclusions:

THANK YOU FOR YOUR ATTENTION